EFFICIENCY BY THE RETARDATION METHOD

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ARMOUR INSTITUTE OF TECHNOLOGY

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Efficiency by the
retardation method

EFFICIENCY

BY THE

RETARDATION METHOD

A THESIS

PRESENTED BY

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WALTER W. DREW
GUY E. WILLIAMS
LYTLE L. WILLIAMS

TO THE

PRESIDENT AND FACULTY

OF

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HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

MAY 1911

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(2). Swenson and Frankenfield, Vol. 2, pp 180-181.

(3). Smith, Vol. 2, p 231.

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22740

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THEORY.

A very convenient method of determining the efficiency of a generator or motor is the retardation method. The machine is brought to its highest safe speed, the excitation is adjusted to that value which it normally has at the load at which the efficiency is desired, the driving power is cut off without disturbing the excitation, and the machine gradually slows down as its stored kinetic energy is overcome by the iron and friction losses. The instantaneous speeds are measured at intervals throughout the retardation and a Retardation Curve is plotted with speeds as ordinates and times as abscissae. Runs are taken with different values of excitation and other retardation curves are plotted. From these curves we obtain the

Efficiency Curve as will be explained later.

This method does not give reliable results when applied to small machines, because they slow down too quickly; but with large machines, where the moment of inertia is considerable, the results are very satisfactory.

The energy E stored in a body rotating with an angular velocity ω is

$$E = 1/2\ \omega^2\ K \qquad (1)$$

where K is the moment of inertia of the body. It is difficult to calculate the moment of inertia of a body such as an armature so that it is desirable to transform equation (1) into one that is more convenient. The angular velocity ω is proportional to n, the speed in revolutions per minute, or

$$\omega = a\ n$$

where a is a constant. Substituting we obtain

$$E = 1/2\ a^2\ n^2\ K$$

and since K is a constant

$$E = 1/2\ C\ n^2 \qquad (2)$$

where C is a constant proportional to the moment of inertia K.

The kinetic energy stored in the rotating armature is reduced by the iron and friction losses only. Hence the rate of change of stored energy is a measure of the iron and friction losses W, so that

$$W = \frac{d\ \frac{C\ n^2}{2}}{dt} \qquad (3)$$

and

$$W\ dt = d\ \frac{C\ n^2}{2} \qquad (4)$$

which expresses that the decrease in kinetic energy, during the infinitesimal time dt, is equal to the work performed by the armature in the same interval in overcoming the losses W. Differentiating we obtain

$$W\,dt = C\,n\,dn \qquad (5)$$

or

$$W = C\,\frac{n\,dn}{dt} \qquad (6)$$

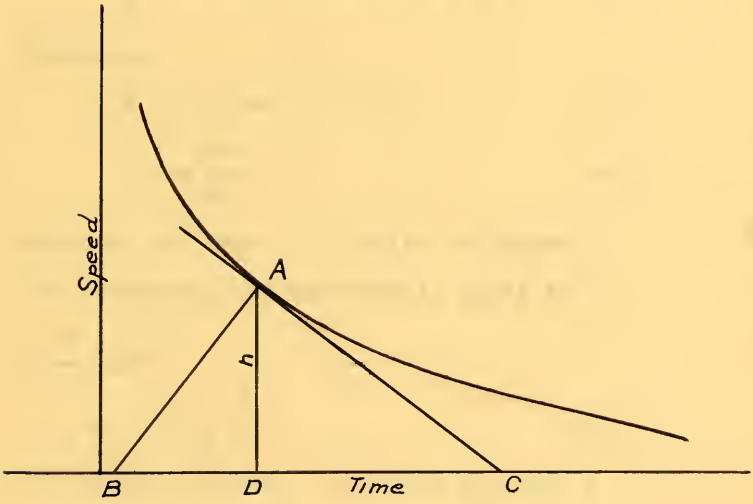


Figure 1.

In the retardation curve shown in Figure 1 the ratio dn/dt is the tangent of the angle A C B, the line A C being tangent to the retardation curve at the point A where the speed is n. If A B is normal to the curve, the angle D A B is equal to the angle A C B and

$$\frac{D\ B}{A\ B} = \tan D\ A\ B = \tan A\ C\ B \qquad (7)$$

Therefore

$$D\ B = A\ B \tan A\ C\ B \qquad (8)$$

$$= n \frac{dn}{dt} \qquad (9)$$

Hence we see that D B, which is known as the subnormal, is numerically equal to

$$n \frac{dn}{dt}$$ and

$$W = C\ (D\ B) \qquad (10)$$

or the instantaneous loss W at a speed n is proportional to the length of the subnormal to the retardation curve at the point where the speed is n.

Having made the retardation runs we determine the value of the constant C by either

of two methods,

(1) The value of the loss W is determined.

(2) The value of the loss W is changed by a known amount w.

In the first method we select one of the retardation curves, and using the same value of excitation as was used in obtaining this curve, we drive the machine, either electrically or mechanically, at a constant speed n, measuring the armature power input. If driven mechanically, the iron and friction loss W is of course the armature power input, which in turn is the output of the driving machine. This driving machine may conveniently be a calibrated motor. If driven electrically as a motor, the armature power input must be diminished by the armature copper loss to obtain the iron and friction loss W. We next measure the length of the subnormal to the retardation curve at the point where the speed is n. Knowing W and the length of the subnormal we can calculate C from equation (10).

In the second method we select a retardation curve and take an extra retardation run,

of two methods.

(1) The value of the line P_1 is determined.

(2) The value of the line P_1 is changed to a chosen amount ΔP_1.

using the same excitation as was used in obtaining the selected curve, but with an additional known load w put on the machine. We then have

$$W = C\ (D\ B) \tag{10}$$

and

$$W + w = C\ (D_1\ B_1) \tag{11}$$

where D B and D_1 B_1 are the subnormals to the selected and new retardation curves respectively at the same speeds n. Eliminating we get

$$C = \frac{w}{D_1 B_1 - D\ B} \tag{12}$$

The load w may be obtained by closing the armature on an adjustable resistance and keeping the output constant by means of a wattmeter. Another method is to apply a prony brake with a definite torque. With either method w can be kept constant throughout a limited range of speed only. This is unimportant as only one point on the curve is necessary.

The question is frequently asked, "Is the constant C the same for all values of excitation?". Obviously it is the same as it is dependent only on the moment of inertia of the rotating body.

Having obtained the retardation curves and the value of the constant C we proceed as follows to obtain the efficiency curve. At a point on each curve corresponding to the normal speed of the machine we construct the subnormal and measure it. Multiplying the lengths of these subnormals by the constant C gives us the iron and the friction losses corresponding to the different excitations. To these losses we add the corresponding armature and field copper losses; and knowing the outputs of the machine for the various excitations we calculate the efficiencies for the various outputs from the equation

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{Total Losses}} \qquad (13)$$

METHOD OF PROCEEDURE.

The retardation method, when applied to the particular set tested, became rather involved due to the unusual combination of machines. The set consists of a synchronous motor direct connected to two compound interpole direct current generators connected in series. These generators are exactly alike in construction and rating and are flat compounded, hence their shunt field currents are constant for all loads. Although assumed to be so, their excitations are not constant for all loads due to the effect of the series turns. Therefore, in assuming that the iron loss is constant for all loads we are in error; but we can make no correction because of the unknown value of series excitation. Since the synchronous motor is used for power factor regulation, its excitation is variable. The conditions of the test made it impossible to determine the values of excitation throughout the range of load, for any assumed power factor. Therefore it was necessary to assume

this excitation constant. Obviously, in making this assumption, we will obtain a total iron loss that is constant, which we know is not true.

In taking the retardation runs the series connection of the direct current generators was broken and the set was started and brought to speed by means of the synchronous motor, which starts as an induction motor. When the synchronous motor was in step it was suddenly disconnected from the alternating current system, and one of the direct current generators, with its series field but not its interpole field, disconnected, was connected to a direct current source of supply. The direct current generator, operating as a shunt interpole motor, was then used to adjust the speed of the set to any desired value. The direct current supply system, not being of sufficient capacity for starting purposes, made it necessary to start by means of the synchronous motor.

Having brought the speed to the highest safe value, retardation runs were taken under the following conditions.

(1) No fields.

(2) One direct current generator field only.

(3) Synchronous motor field only.

(4) Synchronous motor short circuited with sufficient field to give full load current.

The first run gave the total friction and windage loss.

The second run gave the total friction and windage loss plus the iron loss of one direct current generator. This iron loss is obtained by subtracting the friction and windage loss in run (1) from the total loss in run (2). The iron loss for both generators will then be twice this quantity.

The third run gave the total friction and windage loss plus the iron loss of the synchronous motor. This iron loss is obtained

by subtracting the friction and windage loss in run (1) from the total loss in run (3).

The fourth run gave the total friction and windage loss plus the synchronous motor armature copper loss. This armature copper loss is obtained by subtracting the friction and windage loss in run (1) from the total loss in run (4). The iron loss in this run is negligible because of the very small field.

In runs (1) and (4) the inputs to the direct current machine, at normal speed, were measured before the machine was disconnected from the direct current supply system. In run (1) the input is the sum of the friction and windage loss for the set, the iron loss for one direct current machine, and the armature copper loss for one direct current machine. In run (4) the input is the sum of the friction and windage loss for the set, the iron loss for one direct current machine, the armature copper loss for one direct current machine, and the armature copper loss for the synchronous motor,

neglecting the synchronous motor iron loss . The inputs measured did not include any of the field copper losses. We are justified in assuming that the friction and windage loss of the set, the iron loss of one direct current machine, and the armature copper loss of one direct current machine are the same in both runs, because the increased losses in the direct current machine, due to the short circuit current, are negligible. Therefore, subtracting the input of run (1) from the input of run (4) we obtain the magnitude of the synchronous motor armature copper loss. This loss is practically constant as shown below, so that we can obtain the constant C for the retardation curve by method (2), the additional known load w in equation (12) being the armature copper loss.

In an alternating current circuit the current I is given by the equation

$$I = \frac{E}{\sqrt{R^2 + X^2}} \qquad (14)$$

where E is the voltage, R the resistance, and X the reactance. The reactance is inductive so that

$$X = 2\pi f L \qquad (15)$$

where f is the frequency and L the inductance. Therefore

$$I = \frac{E}{\sqrt{R^2 + (2\pi f L)^2}} \qquad (16)$$

The field to produce the short circuit current is very small, hence we are working on the straight part of the magnetization curve. This being so, E is proportional to f and

$$E = b f \qquad (17)$$

where b is a constant. Therefore

$$I = \frac{b\ f}{\sqrt{R^2 + (2\pi f\ L)^2}} \qquad (18)$$

In comparison with the reactance of the armature the resistance is very small for normal frequency and

$$I = \frac{b}{2\pi L} \qquad (19)$$

which is a constant.

$$I = \frac{E}{R}$$

EFFICIENCY FORMULA.

Let

P_1 = friction and windage loss of the set.

P_2 = iron loss of one direct current generator.

P_3 = iron loss of synchronous motor.

P_4 = armature copper loss of one direct current generator.

P_5 = armature copper loss of synchronous motor.

P_6 = field copper loss of one direct current generator.

P_7 = field copper loss of synchronous motor.

$$\text{Eff.} = \frac{\text{Output}}{\text{Output} + P_1 + 2P_2 + P_3 + 2P_4 + P_5 + 2P_6 + P_7}$$

CALCULATIONS.

Determination of Constant C. See Plates (2) & (5).

Input in run (1). Plate (2) 10.455 KW.

Input in run (4). Plate (5) 13.409 KW.

Difference, A.C. Motor copper loss w 2.954 KW.

Length of subnormal, run (1), normal speed. (D B) 34.3 cm.

Length of subnormal, run (1), normal speed. (D_1B_1) 45.0 cm.

From equation (12)

$$C = \frac{w}{D_1B_1 - D\,B} = \frac{2.954}{45 - 34.3} = 0.276$$

Calculation of Friction and Windage Loss.

See Plate (2).

Length of subnormal, run (1), normal speed. (D B) 34.3 cm.

$P_1 = .276\ (34.3) =$ 9.467 KW.

Calculation of Iron Loss for one Direct Current Generator. See Plate (3).

Length of subnormal, run (2), normal speed. 39.1 cm.

$P_1 + P_2 = .276\ (39.1) =$ 10.792 KW.

$P_2 = 10.792 - 9.467 =$ 1.325 KW.

Calculation of Iron Loss of Synchronous Motor. See Plate (4).

Length of subnormal, run (3), normal speed. 54.1 cm.

$P_1 + P_3 = .276\ (54.1) =$ 14.932 KW.

$P_3 = 14.932 - 9.467 =$ 5.465 KW.

Calculation of Armature Copper Loss of one Direct Current Generator.

$P_4 = I_{ga}^2 R_{ga} =$ 2.959 KW.

I_{ga} = armature current. Full Load = 272 Amp.

R_{ga} = armature resistance from table (9) = .04 Ohms.

Calculation of Armature Copper Loss of Synchronous Motor. See Plate (5).

Length of subnormal, run (4), normal speed. 45.0 cm.

$P_1 - P_5 = .276\ (45.0) =$ 12.421 KW.

$P_5 = 12.421 - 9.467 =$ 2.954 KW.

P_5 is also represented by the quantity $3/2\ I_{ma}^2\ R_{ma}$

I_{ma} = full load arm. current=27.2 Amp.

$2\ 954 = 3/2\ I_{ma}^2\ R_{ma} =$

$3/2\ (27.2)^2\ R_{ma}$

R_{ma} = motor arm. res. = 2.62 Ohms.

Hence we can calculate the armature copper loss for all loads.

Calculation of Field Copper Loss of one Direct Current Generator.

$P_6 = I_{gf}^2\ R_{gf} =$ .980 KW.

I_{gf} = gen. field current = 3.5 Amp.

R_{gf} = (from table (9)) = 80.0 Ohms.

Calculation of Field Copper Loss of Synchronous Motor.

$P_7 = I_{mf}^2 \ R_{mf} =$ .704 KW.

I_{mf} = Motor field current = 8.0 Amp.

R_{mf} =(from table(9)) = 11.0 Ohms.

These losses for various loads are shown graphically in Plate (7). All above calculations are for full load.

Westinghouse Elec. and M'f'g. Co.,

Direct Current Generator.

75 KW. 275 Volts. 272.7 Amp.

1200 Rev. per Min.

798037.

Rating of East Machine.

Westinghouse Elec. and M'f'g. Co.,

Synchronous Motor.

200 KVA 4000Volts 1200 Rev. per Min.

3 Phase 28.9 Amp/Phase

798034.

Rating of Synchronous Motor.

Westinghouse Elec. and M'f'g. Co.,

Direct Current Generator.

75 KW. 275 Volts. 272.7 Amp.

1200 Rev. per Min.

798036.

Rating of West Machine.

TO THE PRESIDENT AND FACULTY OF ARMOUR INSTITUTE OF TECHNOLOGY THIS THESIS IS RESPECTFULLY SUBMITTED.

E. E. Dobbie
G. E. Williams
W. W. Drew
L. L. Williams

			Average
Amperes	Volts	Res.	Res.
46.4	2.50	.0538	
48.8	2.05	.0420	
49.4	2.30	.0466	
50.6	2.05	.0405	
51.4	2.05	.0399	
59.0	2.35	.0398	
59.6	2.33	.0391	
75.0	2.58	.0344	
75.6	2.63	.0348	
76.2	2.60	.0341	
77.2	2.60	.0337	.0385

Table #1

Data on Resistance of Armature, Interpoles, Series Field and Brushes of East Machine at 90° C.

			Average
Amperes	Volts	Res.	Res.
4	7.80	1.945	
6	11.60	1.932	
5	9.65	1.925	
3	5.70	1.900	1.925

Table #2

Data on Armature Resistance of A.C. Motor.

Amperes	Volts	Res.	Average Res.
.2	13.5	67.5	
.4	26.5	66.25	
.5	33.5	67.0	
.5	33.5	67.0	
.6	40.0	66.7	
.6	40.0	66.7	
.8	53.5	66.8	
.8	53.5	66.8	
1.0	66.7	66.7	
1.0	66.7	66.7	
1.6	107.0	67.1	66.84

Table #3

Data on Resistance of Shunt Field of East Machine when cold.

			Average
Amperes	Volts	Res.	Res.
.2	13.1	65.5	
.4	26.1	65.3	
.5	33.0	66.0	
.8	52.6	65.7	
1.0	65.6	65.6	
1.2	107.3	65.8	65.65

Table #4

Data on Resistance of Shunt Field of West Machine, When Cold.

			Average
Amperes	Volts	Res.	Res.
.2	2.35	11.74	
.4	4.65	11.63	
.5	5.78	11.57	
.8	9.10	11.37	
1.0	11.25	11.25	
1.2	13.35	11.12	11.446

Table #5

Data on Resistance of Field
of A. C. Motor
when Cold.

			Average
Amperes	Volts	Res.	Res.
3	242	80.66	
3	242	80.66	
3	242	80.66	
3	242	80.66	80.66

Table #6

Data on Resistance of Shunt Field of East Machine at Normal Running Temp.

			Average
Amperes	Volts	Res.	Res.
2.86	226	79.02	
2.86	226	79.02	
2.86	226	79.02	
2.86	226	79.02	79.02

Table #7

Data on Resistance of Shunt Field of West Machine at Normal Running Temp.

			Average
Amperes	Volts	Res.	Res.
8.05	86	10.56	10.56

Table #8

Data on Resistance of Field of A.C. Motor at Normal Running Temp.

Machine	Part	Resistance
East	Arm.	.04
West	Arm.	.04
East	Field	80
West	Field	80
A.C.	Arm.	2
A.C.	Field	11

Table # 9

Summary of Resistance

Measurements on all machines

made under running conditions.

FIELD AMP.	TERM. VOLTS.
0	9
.2	20
.3	31
.4	41
.55	50.5
.7	62
.8	70
.9	80
1.0	92
1.1	104
1.3	117
1.4	126
1.5	138
1.65	148
1.8	162
1.95	172
2.1	184
2.2	194
2.4	208
2.6	220
2.8	236
3.0	248
3.2	260
3.4	270
3.7	285
3.8	290

TABLE #10

DATA FOR SATURATION CURVE OF D.C. MACHINES.

Field Amperes	Phase A Volts	Phase B Volts	Average Volts
.6	400	410	405
.9	610	600	605
1.1	700	710	705
1.2	800	806	803
1.5	1000	1000	1000
1.7	1120	1146	1133
2.0	1340	1350	1345
2.6	1650	1660	1655
2.9	1910	1920	1915
3.1	2070	2060	2065
3.4	2260	2250	2255
3.65	2360	2360	2360
3.9	2520	2520	2520
4.2	2670	2670	2670
4.6	2890	2880	2885
4.6	2890	2880	2885
5.05	3080	3080	3080
5.3	3290	3264	3277
6.0	3586	3544	3565
6.8	3930	3904	3917
7.6	4194	4168	4181
7.95	4290	4264	4277
8.65	4490	4464	4477
9.35	4650	4624	4637
10.55	4914	4888	4901

TABLE #11.

DATA FOR SATURATION CURVE OF A.C. MOTOR.

FIELD AMPERES	PHASE A AMPERES	PHASE B AMPERES	AVERAGE AMPERES
.35	2.325	2.340	2,332
.63	3.740	3.720	3.730
.93	5.390	5.410	5,400
1.43	8.150	8.250	8.200
2.54	14.500	14.500	14.500
3.45	19.800	19.750	19.775
3.50	20.150	20.200	20.175
4.15	23.700	23.800	23.750
4.95	28.650	28.500	28.575

TABLE #12

DATA FOR SHORT CIRCUIT CURVE OF A.C. MOTOR.

Speed	Volts	Amps.	K.W.
1197	255	41	10.455

Time Seconds	Speed R.P.M.
0	1360
05	1300
10	1230
15	1160
20	1100
25	1030
30	975
35	915
40	860
45	800
50	750
55	700
1:00	640
05	600
10	550

Time Seconds	Speed R.P.M.
1:15	503
20	459
25	419
30	375
35	338
40	300
45	266
50	231
55	187
2:00	160
05	130
10	100
15	60
Stop 2:23	0

TABLE #13

DATA FOR NO-FIELD RETARDATION RUN.

SPEED	VOLTS	AMPS.	K.W.
1204	254	45	11.43

TIME SECONDS	SPEED R.P.M.
0	1410
05	1350
10	1275
15	1200
20	1125
25	1060
30	990
35	920
40	865
45	810
50	750
55	700
1:00	
05	594
10	547

TIME SECONDS	SPEED R.P.M.
1:15	500
20	453
25	412
30	365
35	312
40	284
45	244
50	
55	
2:00	133
05	103
10	75
15	
2:18	0

STOP.

TABLE # 14.

DATA FOR ONE D.C. FIELD RETARDATION RUN.

Speed	Volts	Amps.	K.W.
1202	254	65	16.58

	Time Seconds	Speed R.P.M.
	0	1335
	05	1235
	10	1135
	15	1025
	20	940
	25	850
	30	760
	35	
	40	600
	45	531
	50	462
	55	400
	1:00	331
	05	275
	10	170
	15	140
	20	100
	25	
Stop *	1:26	0

TABLE # 15.

DATA FOR A.C. MOTOR FIELD RETARDATION RUN.

SPEED	VOLTS	AMPS.	K.W.
1200	253	53	13.409

PHASE A AMPERES	PHASE C AMPERES	AVERAGE AMPERES
28.75	28.75	28.75

TIME SECONDS	SPEED R.P.M.
0	1229
05	1160
10	1075
15	980
20	900
25	820
30	720
35	625
40	538
45	456
50	359
55	241
1:00	
05	0

Stop →

TABLE # 16.

DATA FOR A.C. MOTOR SHORT CIRCUIT RETARDATION RUN.

Speed	Volts	Amps.	K.W.
1200	255	41.1	10.48

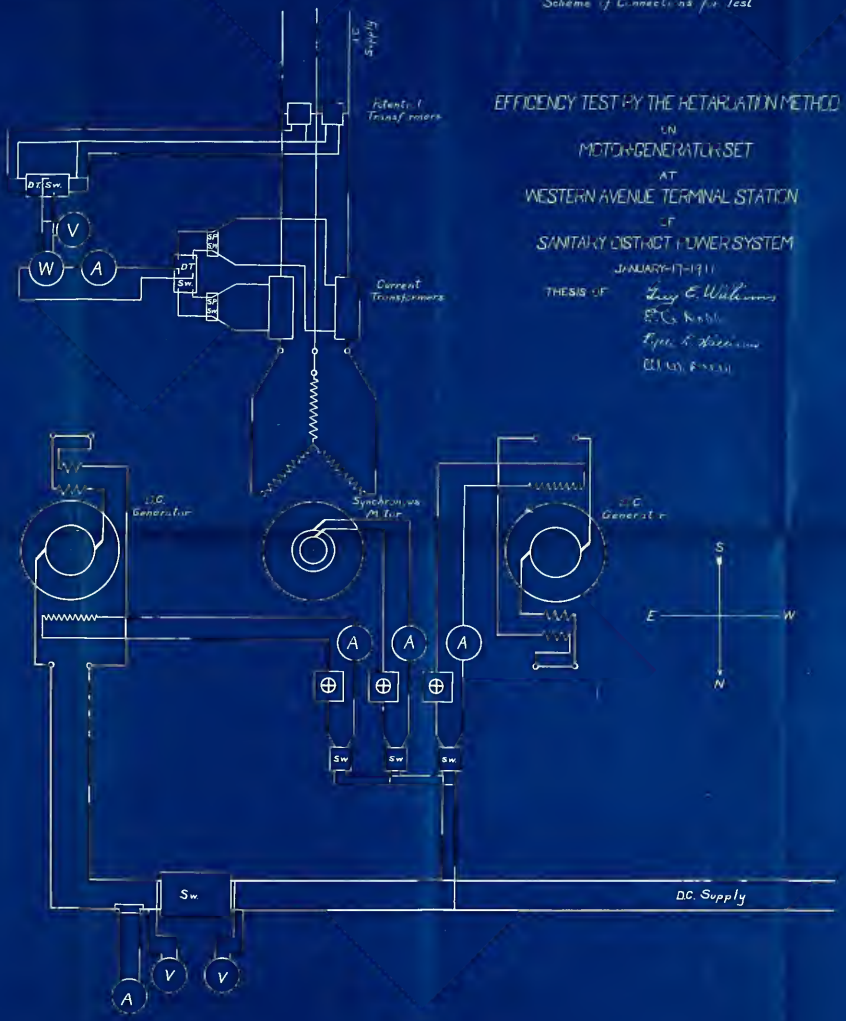
Field on D.C. Motor
only.

Speed	Volts	Amps.	K.W.
1200	254	45	11.39

Field on both D.C. Machines.

Table # 17.
Data for determining Iron
Loss of D.C. Machine
As Motor.

Scheme of Connections for Test



EFFICENCY TEST BY THE RETARDATION METHOD

ON

MOTOR-GENERATOR SET

AT

WESTERN AVENUE TERMINAL STATION

OF

SANITARY DISTRICT POWER SYSTEM

JANUARY 17-1911

THESIS OF Guy E. Williams

E. G. Noble

Egbert K. Hazelton

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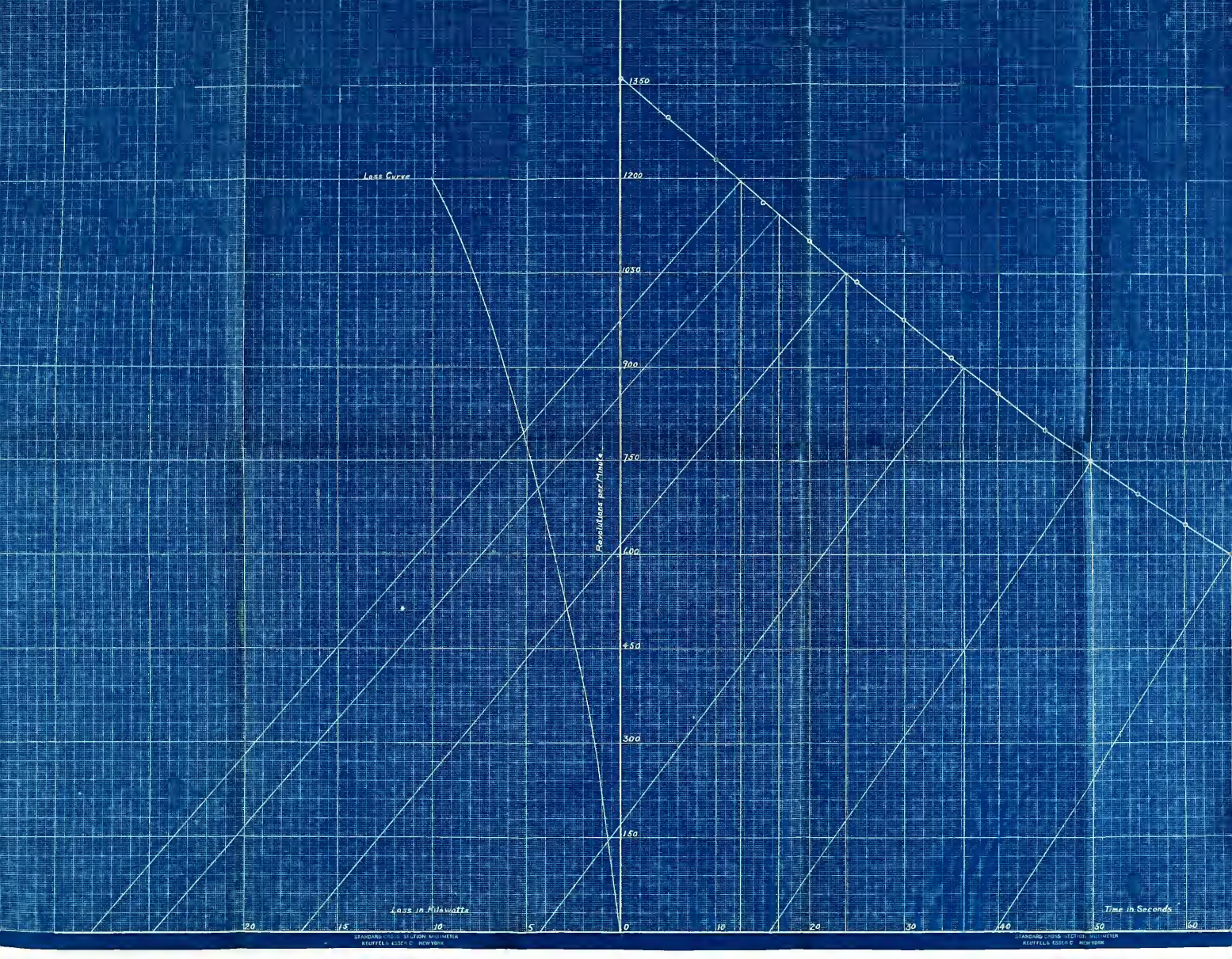
Loss Curve
1350
1200
1050
900
750
600
450
300
150
0
Revolutions per Minute
20
15
10
5
Loss in Kilowatts
0
10
20
30
40
50
60
Time in Seconds
STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO NEW YORK
STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO NEW YORK

Retardation Curve
Fast in shaft

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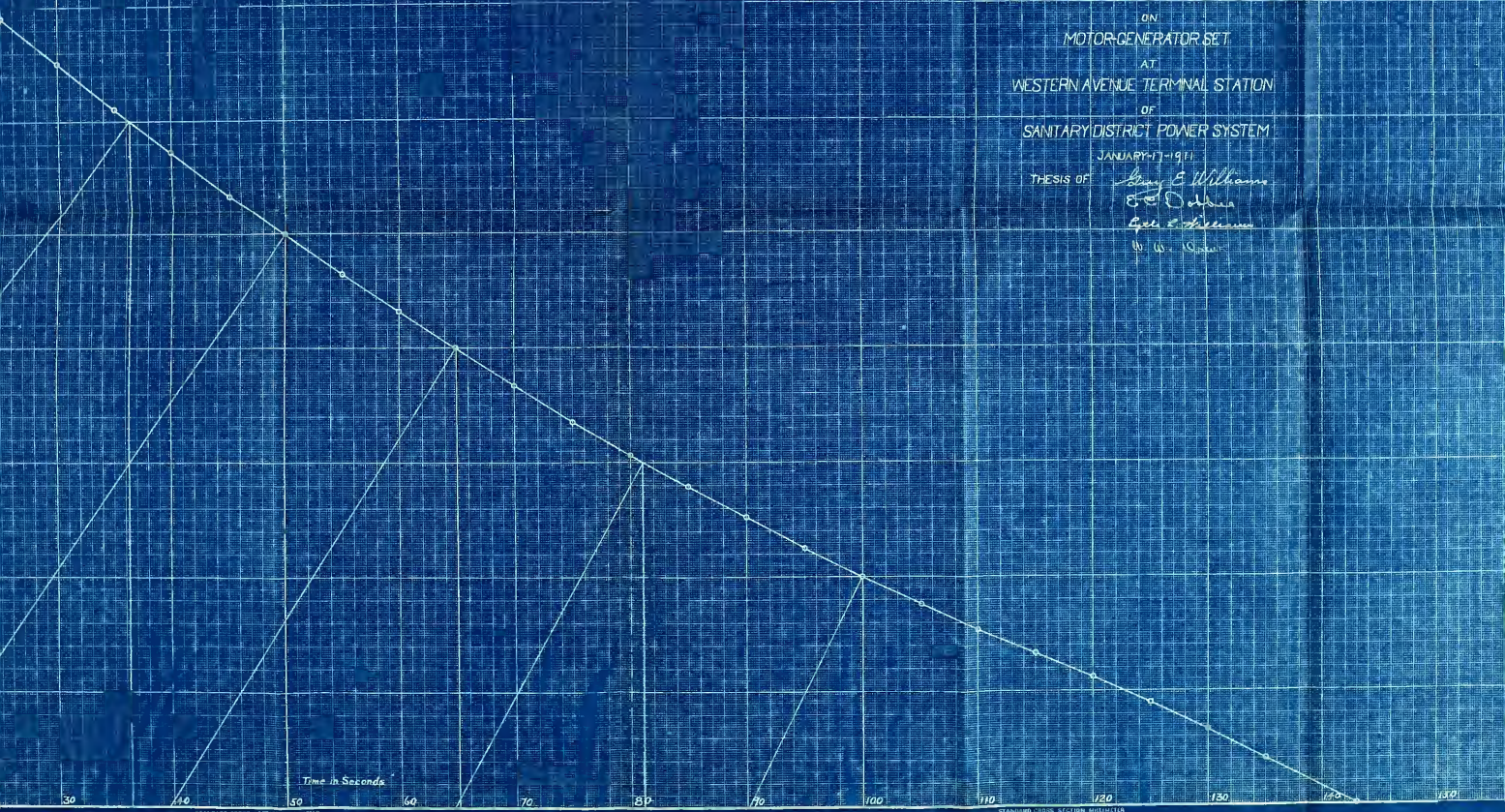
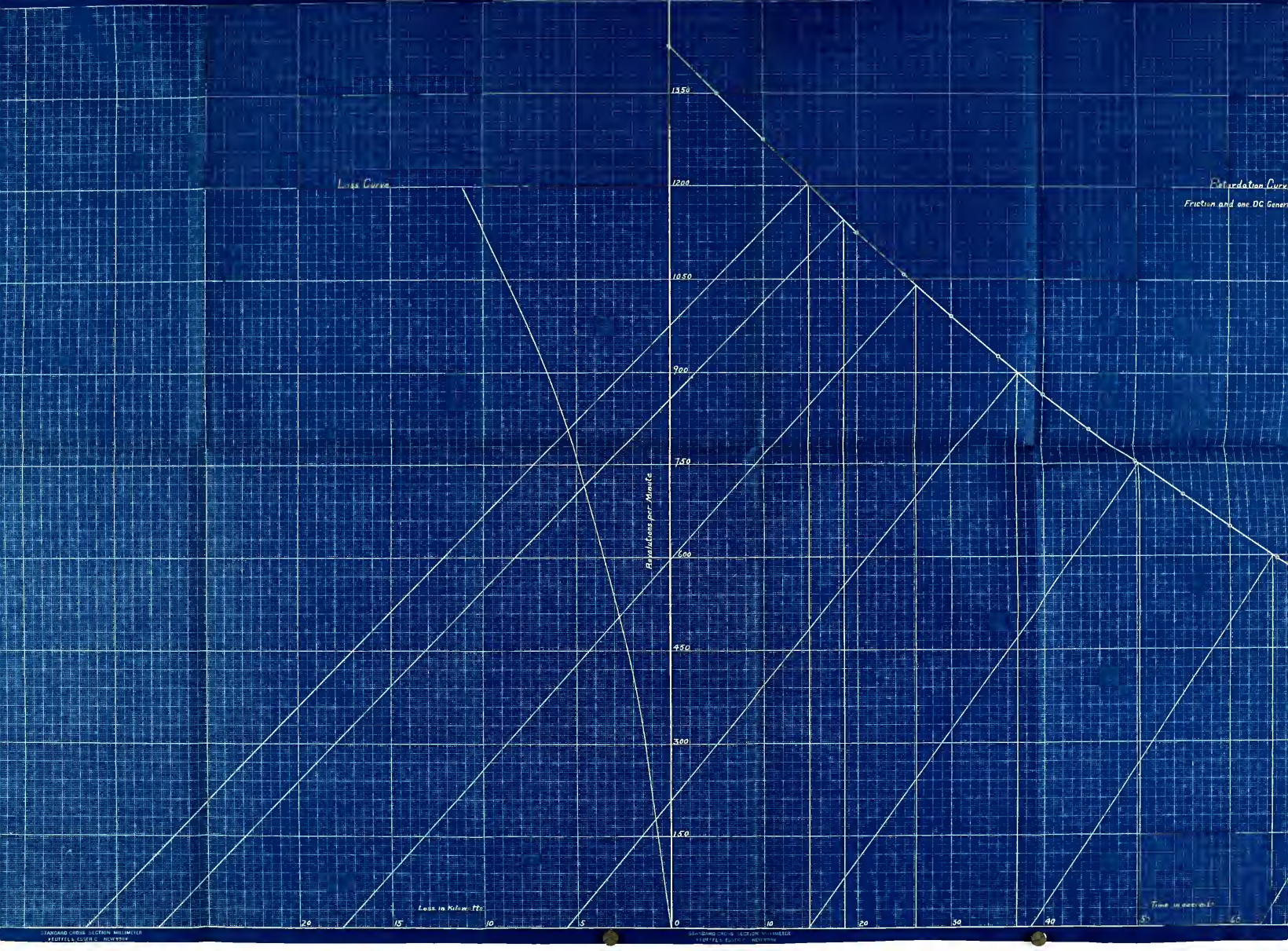
Geo. E. Hansen
W. W. Cook



STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO. HOBOKEN


Loss Curve
Excitation Curve
Friction and one DC Generator
1350
1200
1050
900
750
600
450
300
150
Revolutions per Minute
Loss in Kilow. Hr.
20
15
10
5
0
10
20
30
40
50
60
Time in minutes

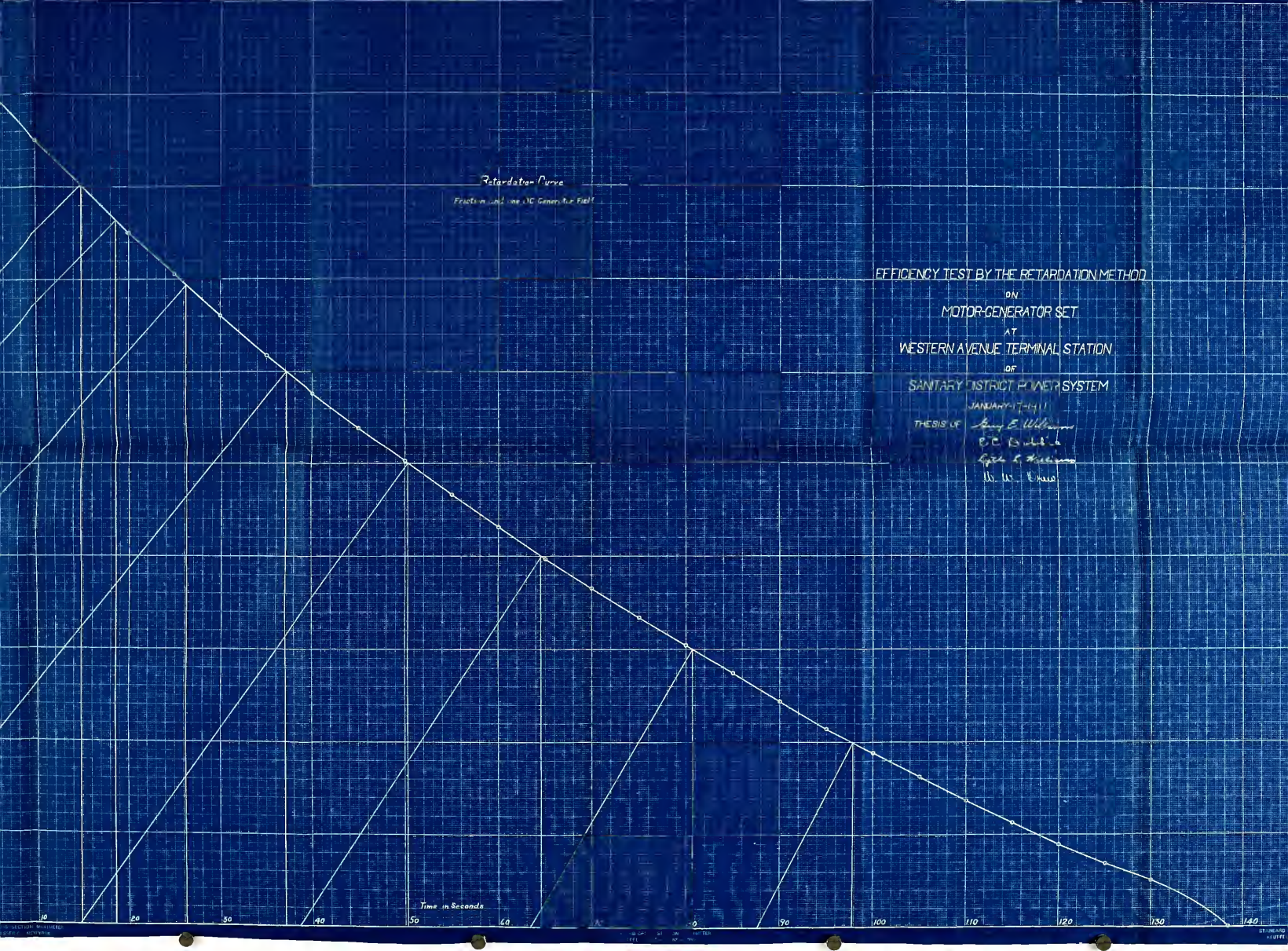
Retardation Curve

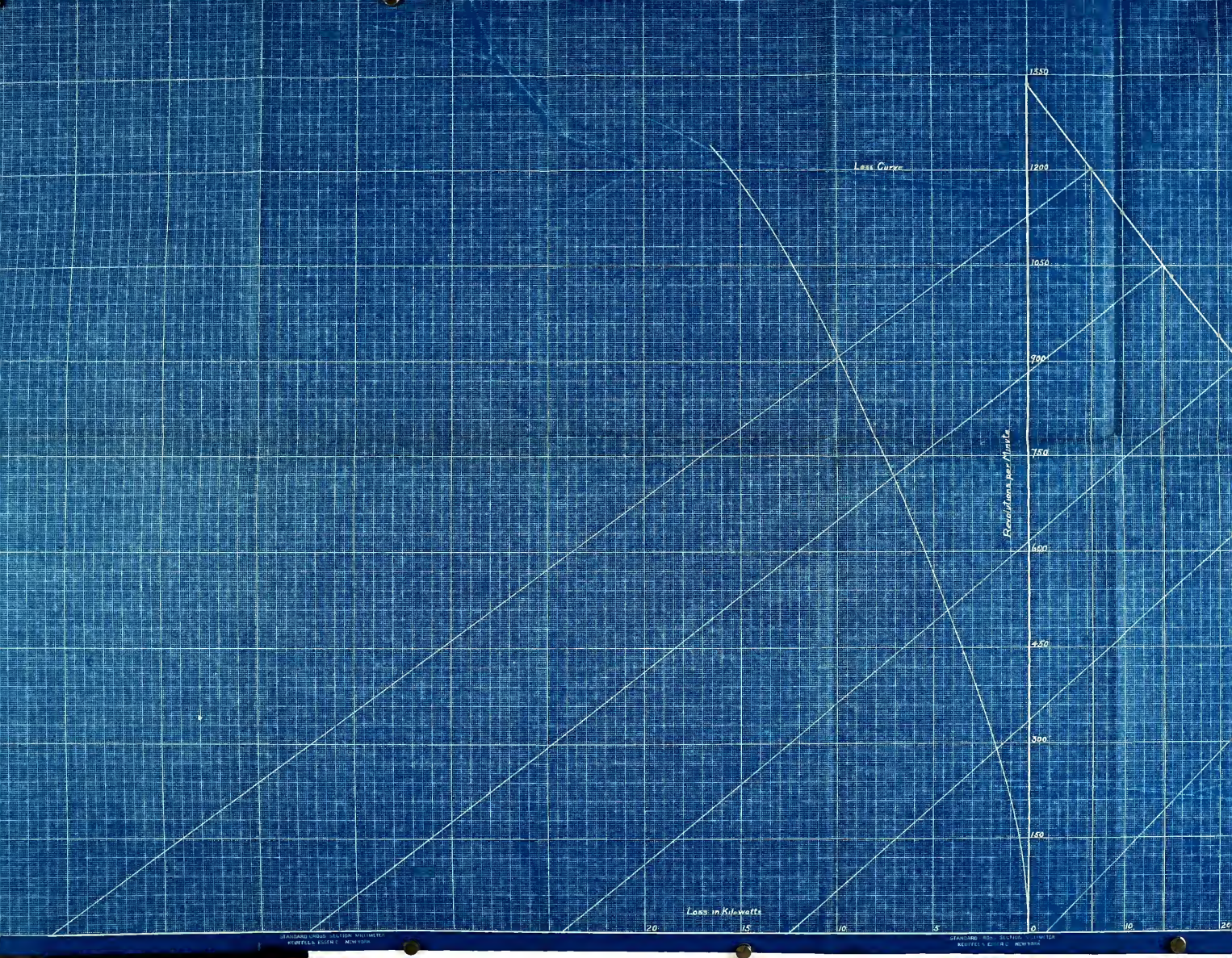
Friction and Core Loss Generator Field

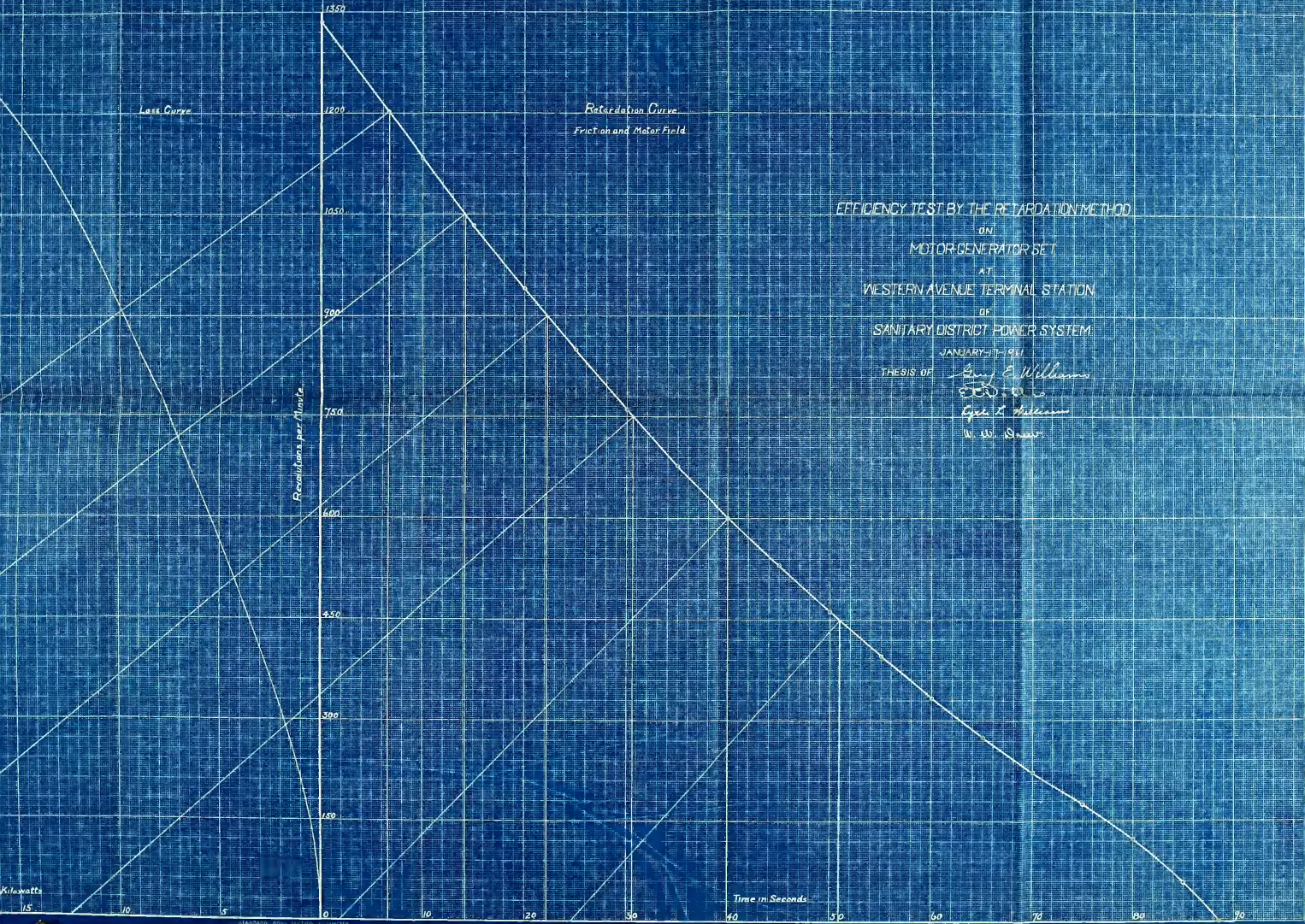
EFFICENCY TEST BY THE RETARDATION METHOD
ON
MOTOR-GENERATOR SET
AT
WESTERN AVENUE TERMINAL STATION
OF
SANITARY DISTRICT POWER SYSTEM

JANUARY 1911

THESIS OF Henry E. Wilkinson
P. C. Bartlett
Egbert K. Hutchinson
W. W. Hall




Loss Curve
1350
1200
1050
900
750
600
450
300
150
Revolutions per Minute
Loss in Kilowatts
20
15
10
5
0
10
20
STANDARD CROSS SECTION MULTIMETER
KEUFFEL & ESSER CO NEW YORK



EFFICIENCY TEST BY THE RETARDATION METHOD

ON

MOTOR GENERATOR SET

AT

WESTERN AVENUE TERMINAL STATION

OF

SANITARY DISTRICT POWER SYSTEM.

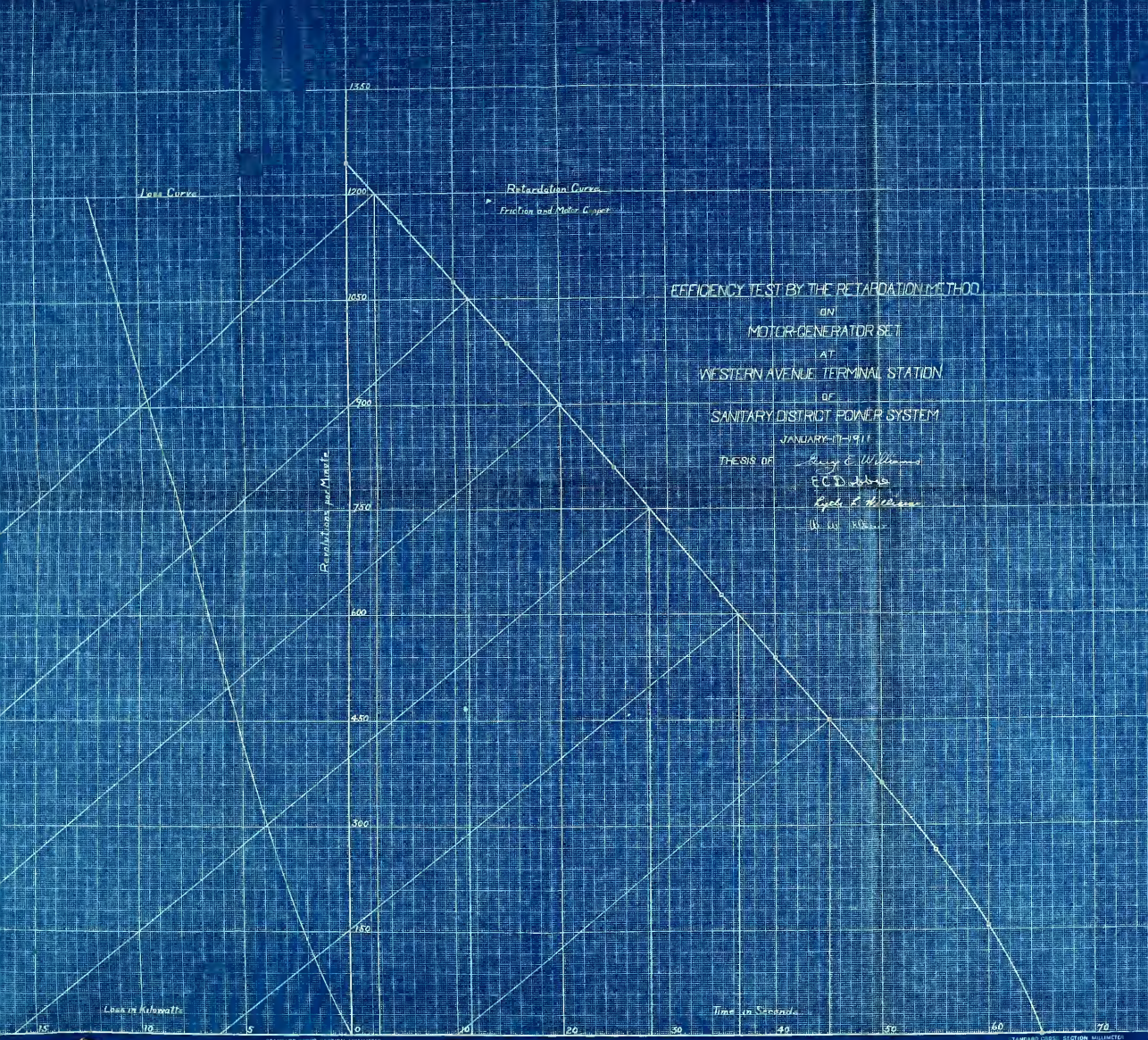
JANUARY 17 1911

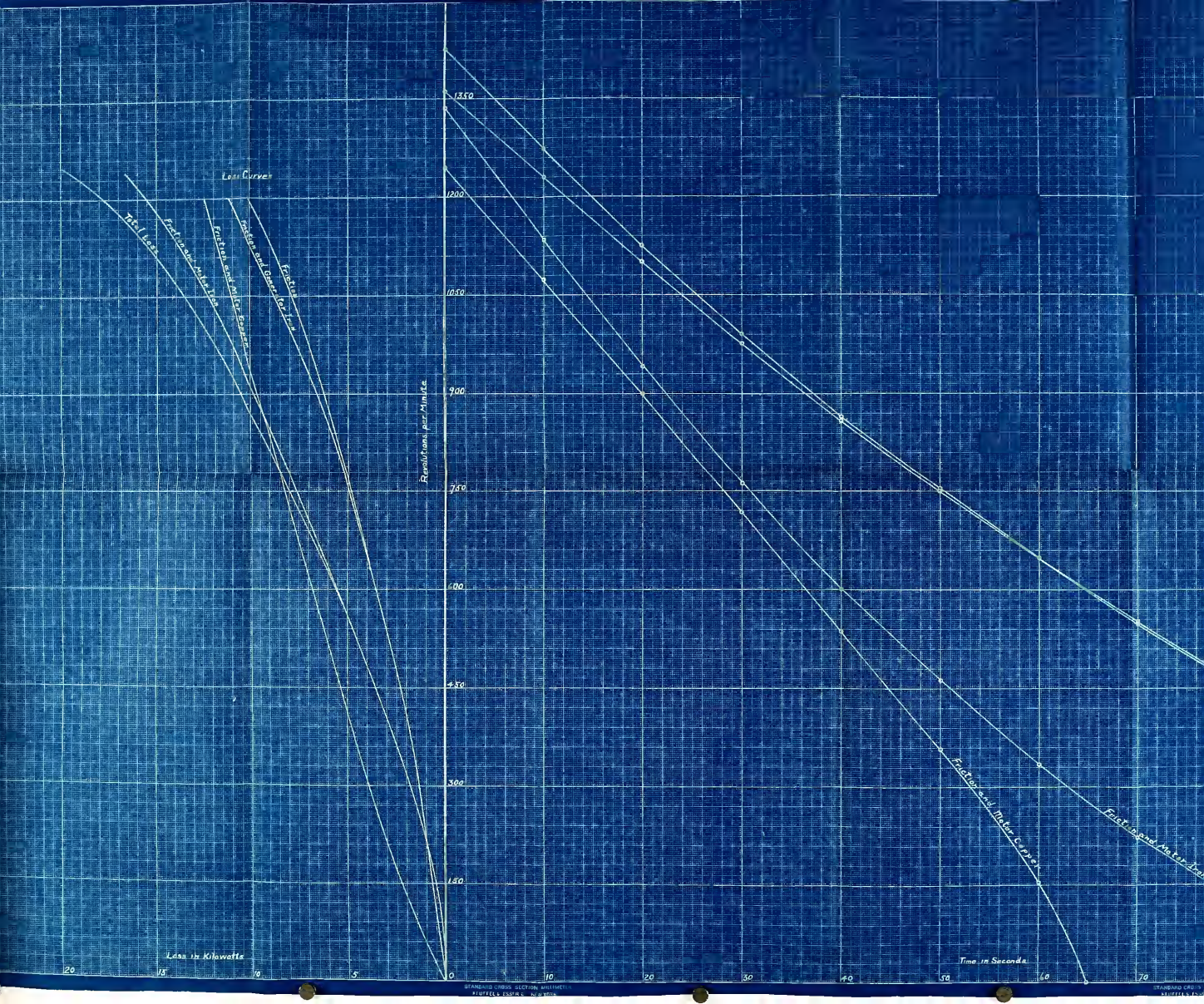
THESIS OF Guy E. Williams

Cyril T. Nickerson

W. W. Swan

STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO. NEW YORK

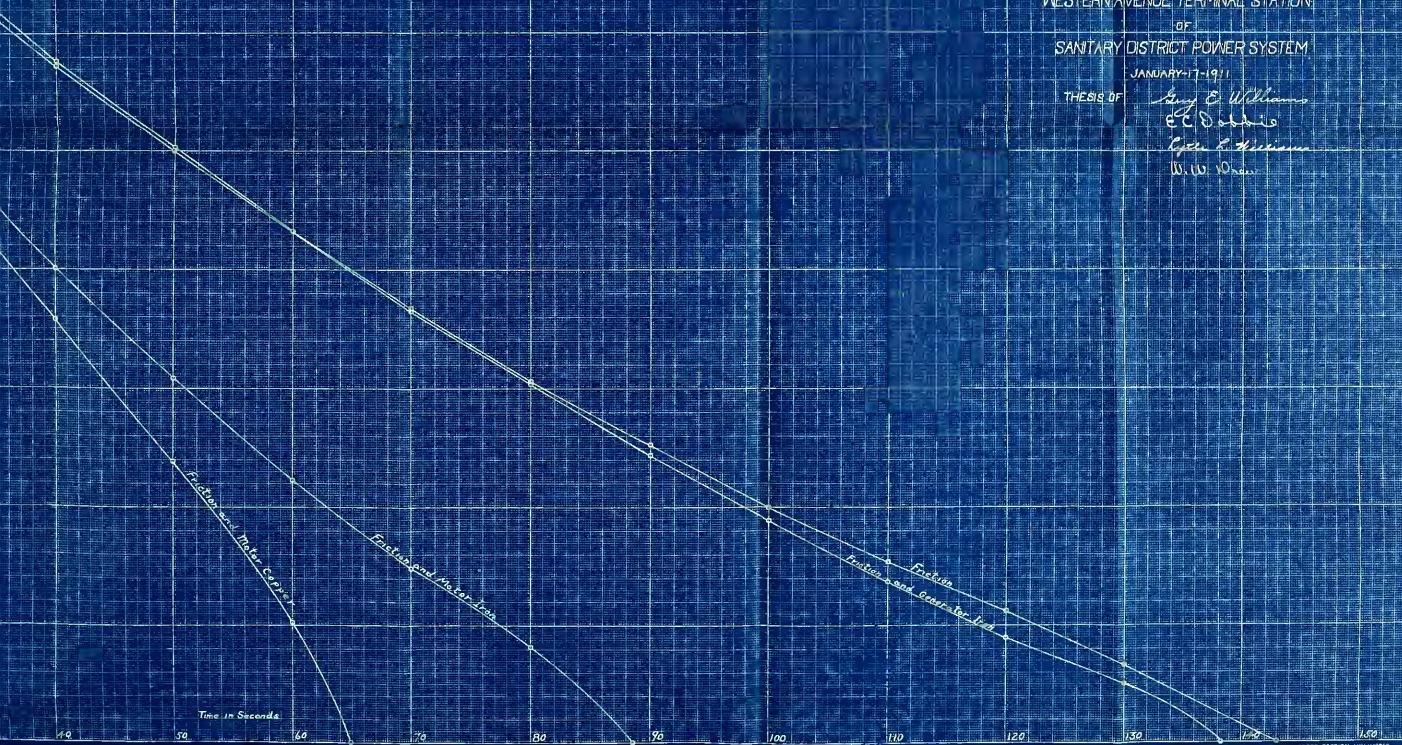

Loss Curve
Retardation Curve
Friction and Motor Curve
Revolutions per Minute
1350
1200
1050
900
750
600
450
300
150
0
Loss in Kilowatts
15
10
5
0
10
20
30
40
50
60
70
Time in Seconds
EFFICIENCY TEST BY THE RETARDATION METHOD
ON
MOTOR-GENERATOR SET
AT
WESTERN AVENUE TERMINAL STATION
OF
SANITARY DISTRICT POWER SYSTEM
JANUARY 17-1911
THESIS OF
E. C. D. Johnson
Ryerson & Williamson
W. W. Wilson


Loss Curves
Total Loss
Friction and Windage Loss
Friction and Core Losses
Friction
Friction and Core Loss
Friction and Windage
Revolutions per Minute
1350
1200
1050
900
750
600
450
300
150
0
Loss in Kilowatts
20
15
10
5
0
Time in Seconds
10
20
30
40
50
60
70

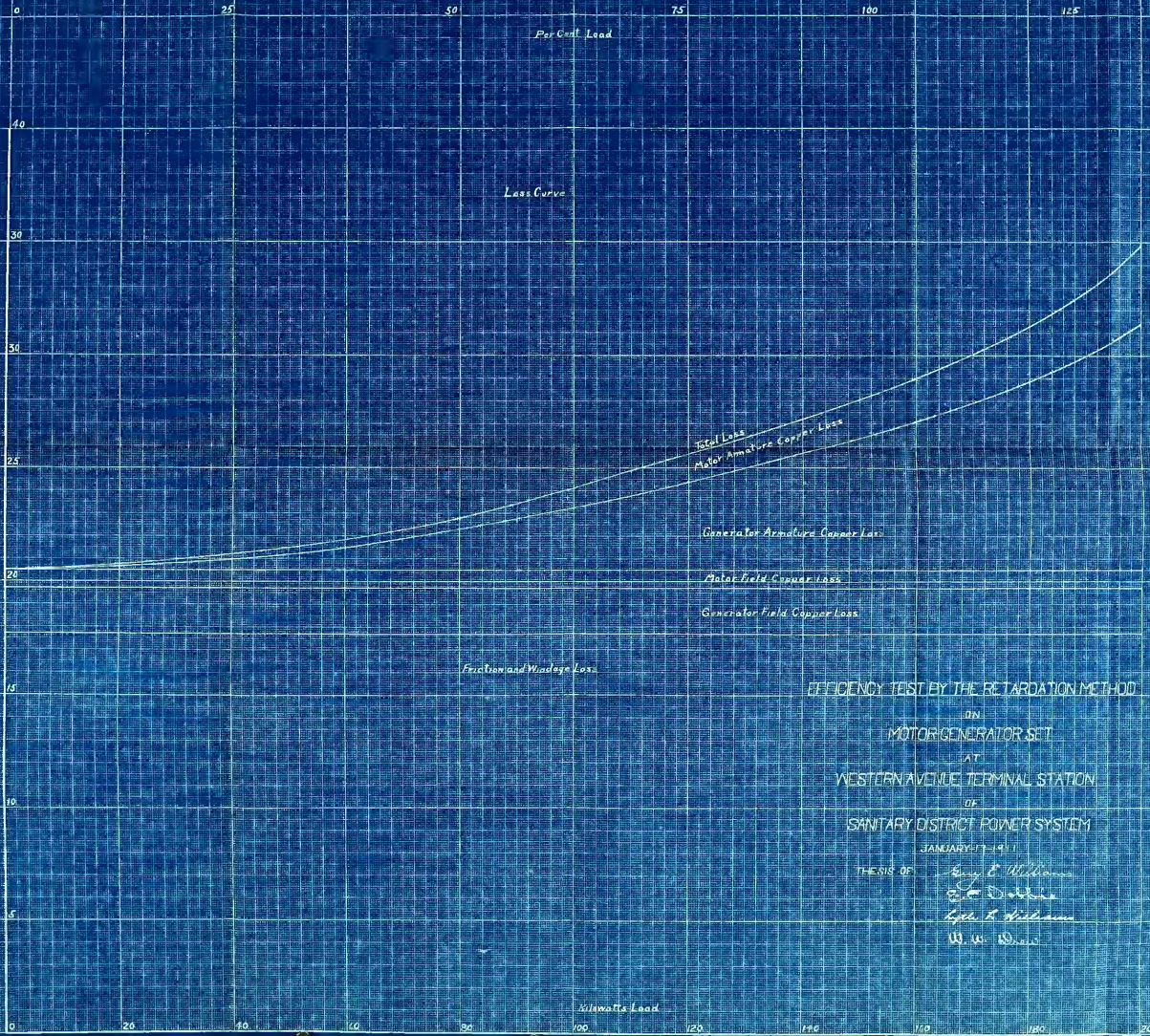
Retardation Curves.

EFFICENCY TEST BY THE RETARDATION METHOD
ON
MOTOR-GENERATOR SET
AT
WESTERN AVENUE TERMINAL STATION
OF
SANITARY DISTRICT POWER SYSTEM
JANUARY-17-1911

THESIS OF Guy E. Williams
E C Dobbs
Tyler E. Hickman
W. W. Horn



STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO. NEW YORK



EFFICIENCY TEST BY THE RETARDATION METHOD

ON

MOTOR GENERATOR SET

AT

WESTERN AVENUE TERMINAL STATION

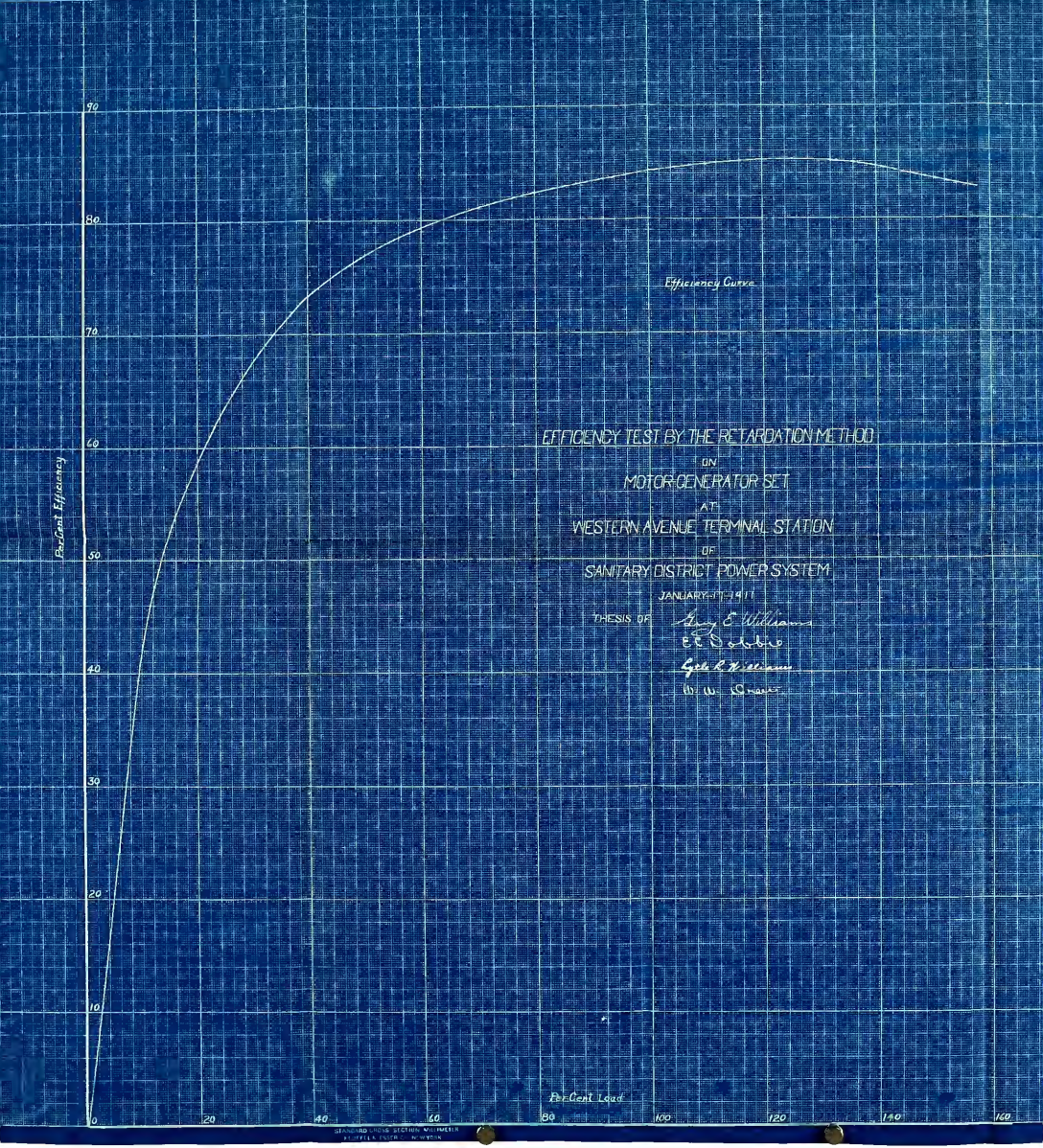
OF

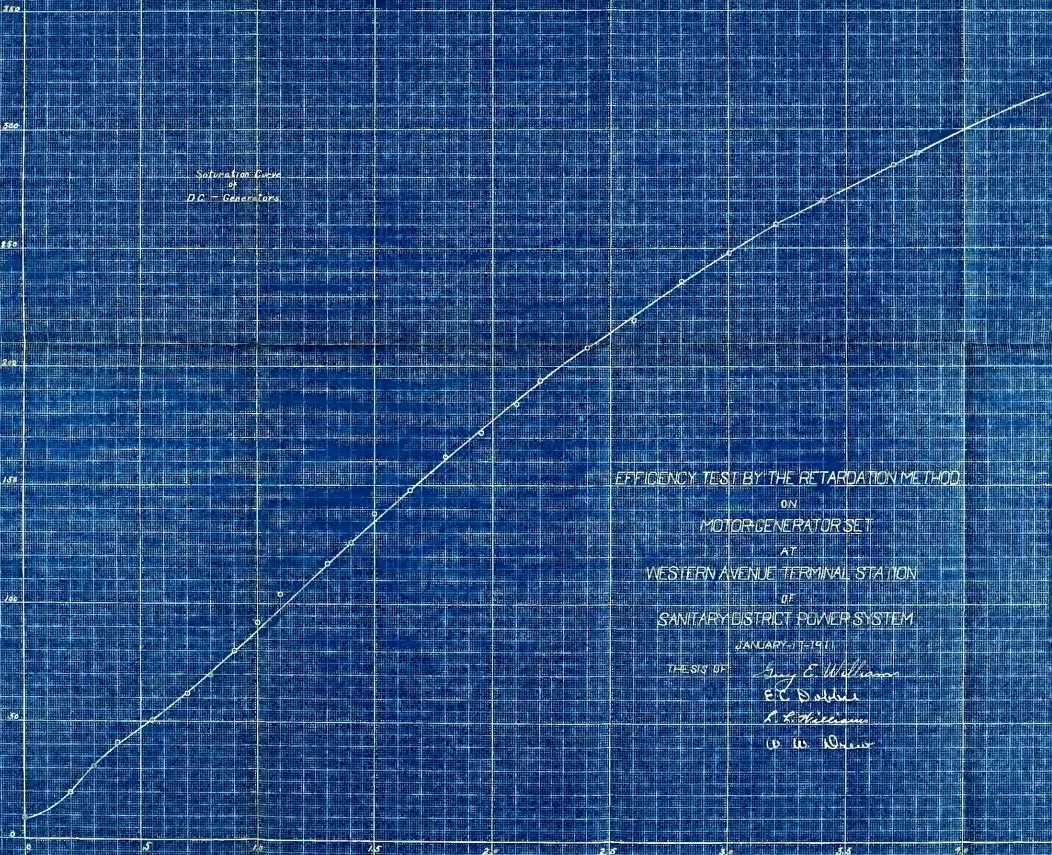
SANITARY DISTRICT POWER SYSTEM

JANUARY 17 1911

THESIS OF

STANDARD CROSS SECTION MILLIMETER
KEUFFEL & ESSER CO NEW YORK


Efficiency Curve
EFFICIENCY TEST BY THE RETARDATION METHOD
ON
MOTOR-GENERATOR SET
AT
WESTERN AVENUE TERMINAL STATION
OF
SANITARY DISTRICT POWER SYSTEM
JANUARY 11, 1911
THESIS OF
Percent Efficiency
Percent Load
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160



EFFICIENCY TEST BY THE RETARDATION METHOD

ON

MOTOR GENERATOR SET

AT

WESTERN AVENUE TERMINAL STATION

OF

SANITARY DISTRICT POWER SYSTEM

JANUARY 17-1911

THESIS OF Guy E. Wallington
E.C. Dahlin
R.F. Wilcox
W.W. Ryan

EFFICIENCY TEST BY THE RETARDATION METHOD

ON

MOTOR-GENERATOR SET

AT

WESTERN AVENUE TERMINAL STATION

OF

SANITARY DISTRICT POWER SYSTEM

JANUARY 13 1911

THESIS OF

E. L. Stahl

C. E. Northwestern

Short Circuit Amperes

Terminal Volts

Field Amperes

Saturation and Short Circuit Curves

E = Synchronous Watts

STANDARD CROSS SECTION MILLIMETER

KEUFFEL & ESSER CO. NEW YORK